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Abstract

Competencies management in the industry is one of the most important keys in order to obtain good performance with production means. Especially in maintenance services field where the different practical knowledges or skills are their working tools. We address, in this paper, the both assignment and scheduling problem that can be found in a maintenance service. Each task that has to be performed is characterized by a competence level required. Then, the decision problem of assignment and scheduling lead to find the good resource and the good time to do the task. For human resources, all competence levels are different, they are considered as unrelated parallel machines. Our aim is to assign dynamically new tasks to the adequate resources by giving to the maintenance expert a choice between the robustest possibilities.

Key words: Competence, Human Resources, Lateness, Maintenance, Scheduling, Tasks Insertions, Uncertainties, Unrelated Parallel Machines

1 Introduction

To stay competitive, companies must decrease their costs as much as possible and optimize their production means operations. In order to support better equipments' availabilities, and through them the company one, the maintenance service intervenes. It deals with problems before or after the breakdowns, at any place. This improvement mainly requires a better management of the workforce and its competencies.

It is difficult to determine precisely the required human resource number in a maintenance service [15]. Indeed, factors making enabling capacity adaptation are prone to uncertainties. Those are due to several parameters (variations of the intervention requests which are never similar, arrival dates of requests, requests' contents, required treatment duration and equipments availabilities as well as elements related to the real intervention treatments). Thus, the different tasks are well known when they occur. The reactivity and the organization of the maintenance service will depend on the importance of the required treatment.

There are mainly two types of maintenance activities: the preventive maintenance, whose activities can be long term planned, and the corrective maintenance which is related to the non foreseeable breakdowns. Within the service of maintenance, employees have different competencies and different qualification levels. Treatment speed and thus the service reactivity will depend on the choice of the employees assigned to the task.

We give in this paper a method to take care of the new tasks apparition and we propose a decision support to insert it in the current schedule. We work on the case where the task assignment has already been

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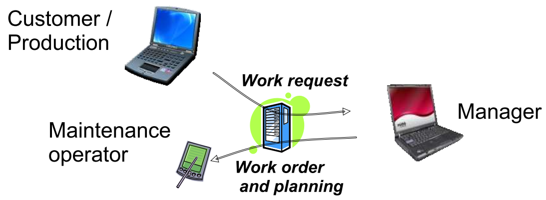

Fig. 1. Database communication

realized (for example with the heuristique presented in [14]). The goal is to disturb as less as possible the current schedule. However, the whole schedules are subject to uncertainties and variation between theory and reality. In order to propose insertion solutions for a new task, we have to determine which places in the schedule are the more flexible in order to obtain a scheduling which would be the most robust (the less sensible to uncertainties). The fact to propose schedule solutions taking care of variation by anticipating show that our scheduling method is proactive.

In this article, we detail a methodology which will allow us to assign tasks to resources by considering disturbances. The rest of the paper is organized as followed: In the second section, we will introduce how maintenance services can be managed. In the third part, we will present our scheduling problem. Then we develop our model and a resolution approach. Finally, we will discuss the different obtained results.

2 MAINTENANCE MANAGEMENT

There are various forms of management of maintenance. Indeed, if the company itself does not assume maintenance, this one can then be sub-contracted. The monitoring, the preventive and corrective maintenance can thus be entrusted directly to the manufacturer of the equipment (expert on this type of equipment) or with a company specialized in industrial maintenance (expert in monitoring and in remote maintenance field but general practitioner as for the monitored equipment). The equipment can also be rented, and if maintenance is not assumed by the user company, it can be sub-contracted too.

2.1 Tasks management

A maintenance service has to answer to its customers service demand. To do so, it disposes of human and material resources. Human resources are all different due to their qualification level in the required technical fields. Human resource being in limited number. Each operator can perform only one task at any time. The duration of a task will depend on the resource assigned to and their competencies. However, all the resources must be occupied. Then it will not necessary be the most efficient resource who will be assigned to the task's treatment. The tasks' assignment corresponds to a succession of tasks within human resources working time.

The maintenance distant management has its own computerized way of communication. When a breakdown occurs, the service asking for a maintenance intervention makes a work request. This one is recorded in the Computerized Maintenance Management Systems databases (CMMS) and contains the problem informations. These informations will help the maintenance service to determine which resource will be assigned to the task treatment.

Regularly, the maintenance service manager collects the work requests in the databases from the expert station (figure 1). The expert station corresponds to the manager work computer on which will be realized the assignment process. When the manager has collected data, with the help of the scheduling program, he assigns tasks. He determines for each maintenance task, the best timing in employees planning. Then he published assignments as work orders in the databases which are consultable on all computers connected to the databases.

2.2 Human resources management

The human resource are not considered as identical, then the assignement decision has to take care of several parameters.

Competencies management
Boumane and al. [5] studied the different competency types which can be generic and used in various professional situations, or specific to the activity. During her thesis, Agnès Letouzey carried out a study on nineteen companies to obtain their opinions on the operators' assignment problem [13]. It shows that operators' management, according to their competencies, is important for industry leaders and that there is still no software taking this into account. 79% of the companies think that operators' management is useful or essential in scheduling. Whereas in current softwares the operational duration is fixed, for the industry leaders, the consideration of the operators' qualification is very important to determine their assignments. For them, the qualification level has (sometimes for 47% of them and always for 27% of them) an influence over the task's duration of realization. It appears the need for further development linking the competencies of human resources and the operational durations like in the determination of the potential of the company. However, if the competency levels of each one are known, an other problem has to be solved : balancing the workload of resources and try reach a compromise between the reactivity and the perturbation due to the modification of the employees planning.

A parallel machine problem
A maintenance service is an environment composed of m operators working in parallel. We assume that all can perform each task, but not with the same efficiency. Moreover, the resource which is the most effective for a task, would not necessary be effective for all tasks.The multiplicity of competencies shows that we have a parallel machine problem, but with unrelated machines which is noted R or $R_m|\ \beta|\ \gamma$,[17] [3].

3 CONTEXT OF THE PROBLEM

In scheduling and planning, the time horizon is often split in periods (the short, medium and long term). Then, we can study events on each time interval and not on a continuous scale of time. The context of this article takes place in the short term horizon. In this approach, we consider that maintenance tasks have to be scheduled when they occur (generally it is the case of corrective maintenance). The manpower is then the limiting factor in the scheduling realization. Human resources are then organized in the maintenance service which has to plan their work.

3.1 Equipment

Within each plant, the maintenance service has to maintain equipment under operation. The level of the results to reach by the maintenance services is generally predetermined. Either a contract is signed between two (or more) partners fixed their cooperation terms, or there is a *moral agreement* inside the compagny between production and maintenance service, that fixe the equipment efficiency required. In both case, the objectives of the maintenance are defined by a level of availability (that can be different from one equipment to another). The guaranteed availability is a percentage of the opening time. This one is located in a range of value (a class). If, for a machine or a group of machines, the objective of availability is not achieved, penalties have to be paid by the service provider. Conditions concerning the penalties are defined while elaborating the contract and are function of the non availability duration. We will consider in our model the minimisation of those penalties.

3.2 Tasks

On medium-term, the maintenance service has to plan and assign the best human resource for the treatment of the different maintenance tasks. Preventive and conditional maintenances have for parameters a known duration, a starting date: r_j and a completion date: d_j. The corrective maintenance tasks generally occurs in the short-term horizon. They also have a duration, which is only evaluated since it depends on a correct diagnosis. Their earliest starting date r_j is not necessarily immediate, since spare parts are not necessarily available (they can be expected from a supplier) or the availability level of the equipment is quite good and then the intervention can be done latter.

These characteristics of maintenance tasks allow us to use the same model. The task j is composed by a face duration p_j and the type of competence required (for example, the competence could be mechanic, electricity, automation or a certification). The competence required will be denoted as an integer value k with ($k = 1...o$). The effective duration of a task j will be known only when we will know the resource that will perform it.

3.3 Human resources

The maintenance service is composed by m human resources ($i = 1...m$), characterized by a competence profile. Relative speeds do not depend only on the tasks. Each resource has a corresponding qualification level for each task. Operators will perform them more or less quickly. The duration of the job j, by the human resource i is denoted by p_{ij}. With:

$$p_{ij} = f(p_j, C_{ik}), \forall i \in \{1, ..., m\} \tag{1}$$

Where C_{ik} is the competence rate of resource i in the competence which is required to achieve the task type k. It can be represented with a matrix in which, for each different kind of job, the rate corresponding to the required competence can be found.

$$\begin{bmatrix} C_{1,1} & \cdots & C_{1,n} \\ \vdots & \ddots & \vdots \\ C_{m,1} & \cdots & C_{m,n} \end{bmatrix}$$

The treatment duration of two different tasks by two different resources enables observing that for one kind of task, a resource can be more powerful than one other, whereas, for the second task, it is the second one which is the most effective.

4 SCHEDULING PROBLEM WITH UNCERTAINTIES

4.1 Problem syntheses

In this problem while tasks have not been really treated, their data are stochastic. In order to propose a robust (and proactive) solution, our simulation will consider variations on release-dates, due-dates and of course on the duration of each tasks within the scheduling.

4.2 Scheduling under uncertainty

In classical scheduling problems, the data are generally supposed to be known and fixed. However, the reality does not check this hypothesis, of course because of variations, but also because a lot of data are only previsions or estimations. Optimal solutions to such scheduling problems which are based on fixed data and do not show the reality, will have only few chances to be applicable and will be subject to modifications.

In the existing model taking into account uncertainty, we find mainly the Davenport and Beck one which present three approaches: proactive, reactive and proactive-reactive approaches [6]. Proactivity is the fact to anticipate disturbances before that they really occur. Reactive approaches work in real time, during the scheduling phases. Proactive-reactive methodologies, will try to combined both approaches in order to take into account uncertainties during all the scheduling life cycle and ensure a maximum of performance [18] [10]. A schedule is robust if this performance is few sensible to data uncertainties and variations [4]. Moreover a schedule has to be flexible to be adaptable to the possible disturbance. We can identify a static flexibility as the temporal flexibility (concerning tasks starting date), the sequential flexibility (which authorises the permutation between tasks, and which supposes the temporal flexibility) or the assignment flexibility (which allows changing of resource after a first assignment). There is also the dynamic flexibility which is the scheduling capacity to adapt itself to disturbances [20].

In this paper, we consider that, in a given schedule, task data are subject to more or less variations in order to be representative of the reality. Earliest and latest starting dates of each task may vary. Indeed, they are obtained from the tasks release-dates and due-dates, and variations on this one introduce modifications on the earliest and latest starting dates. Tasks durations may also be increased or shortened if the task treatment is longer or shorter than envisaged. Finally, the most delicate disturbance, that may happen, is a new task arrival which has to be inserted in the current schedule. Its parameters are of course subject to an estimation, and there precision depend on the diagnosis exactness.

4.3 Tasks insertion problems

We introduce quickly the different work in the literature, that deal with the scheduling disturbance problem. Monostrie and *al.* have made a state of the art of the proactive approaches and reactive approaches with disturbance [16]. Laguna and al. worked on minimizing the weighted lateness on parallel machine. Uncertainties are due to tasks interruptions by stop with a stochastic duration [12]. Sun and al. presented an approach in order to take into account changes in production orders [19]. They propose a reactive and dynamic scheduling methodology in order to modify the current schedule in case of additional work or suppression of existing work. Their approach considers machines breakdowns and employees absenteeism. Kis and al. but also Groflin and al. treat the tasks insertion problem in job-shop. They tried to minimize the scheduling total duration when a new task appears [11] [9]. In the Resource Constrained Project scheduling Problem, knwon as RCPSP, Artigues and al. consider a dynamic approach which is based on a first and static schedule [2]. They take into account two kinds of uncertainties [1]: the duration variation and the fact that new tasks can occurs. A polynomial algorithm has been developed in order to insert new tasks aiming to minimize the makespan increase. A project scheduling bibliography under uncertainties had been published by Herroelen and al. [10]. It considers reactive approaches, robust or proactive approaches and approaches with stochastic data. Their conclusion is: in the project management area, new work in order to develop mechanism to repair reactive schedule would be necessary. Duront and al. presented an approach for the radars management [7]. This approach integrate new tasks in a current schedule. New tasks duration and due-date are really known when the tasks appear, their objectives being to minimize the total lateness.

5 MODEL

5.1 Data

We first describe some notations needed for the explaination of the model. For each task j:

- p_j : face duration of the task j (this duration will be subject to variation depending of the resource assignment),
- d_j : due date of the task j (this value is estimated in function of the current availability of the equipment concerned),
- w_j : penalty which could be claimed if the treatment of the task j is not performed on time.

5.2 Variables

The variables of our problem are the following ones for each task j:

- $t_j \ (j = 1...n)$: starting of the task j,
- $x_{ij} \ (j = 1...n \ and \ i = 1...m)$: 0-1 value representing the tasks assignment. $x_{ij} = 1$ if the task j is assigned to a resource i, else $x_{ij} = 0$,
- $T_j \ (j = 1...n)$: lateness of the task j,
- $ES_j \ (j = 1...n)$: earliest starting date of the task j,
- $LS_j \ (j = 1...n)$: latest starting date of the task j.

5.3 Constraints

Each task has to be assigned only once to only one resource:

$$\sum_{j=1}^{n} x_{ij} = 1, \forall i \in \{1, ..., m\} \tag{2}$$

A task j cannot be planned before the equipment i is available:

$$\forall j, t_j \geqslant r_i \tag{3}$$

5.4 Objectives

In order to consider corrective maintenance, we have to insert dynamically tasks in a current schedule. However it is difficult to insert tasks in a schedule which is subject to variations between the proposed one and the reality. In order to find new task insertion solutions, we have to determine which place are the most flexible and consequently propose the most robust schedule (the less sensible to variations). The fact to propose solutions taking into account variations by anticipating them, signify that our scheduling approach is proactive. Tasks which are finished late decreasing the equipment availability ratio imply that we have to minimize the total weighted tardiness.

$$\min \sum_{j=1}^{n} w_j T_j, \tag{4}$$

The aim of our work beeing to schedule human resources activities, our methodology will take into acount their individual performances to find the best resource for each task. But it will also consider the existing workload in order to distribute activities between employees.

6 PROBLEM RESOLUTION

6.1 Graph modelisation

In our problem, we consider a current schedule (previously computerised). This schedule already integrates n tasks that had been already assigned to m human resource. The current schedule can be modelized as a graph. Its structure is represented on the first picture in the figure 2. The graph is a unit of branches which represent each one the a human resource schedule. They are composed of nodes which represent tasks and arcs which are the potential constraint between to tasks (precedence). The valuation of arcs are the duration of the origine task. Tasks are placed between a fictive beginning task B and fictive end task E. Moreover, each node is linked with the B node. This link is valuated by $r_(i)$ and correspond to the constraint (3). There is no link between branches, because resources work independently. Bellmann long way algorithm can be performed to find earliest starting dates of each task (graph "Earliest Starting Date Graph" on the figure 2).

For finding latest starting time it is necessary to consider the due date of each task. We propose to construct a second graph, in which we keep the same node and the potential constraints as previously, but we add arcs between each task j and the fictive end task E. These new links are valuated, for each task j, by the difference between the branch last task due-date d_B and $d_j - p_{ij}$ (where i is the resource assigned to task j). Then, an adaptation of Bellmann algorithm allows to find (in reverse order) the relative latest starting time LS_j^E. We call LS_j^E, the relative latest starting time, since, for a resource i, it represents the duration between the end of the last task assigned to i and starting time of task j.

In both graphs presented on the right of the figure 2, we can not have any positive circuit, if they would have a lateness, we could not observe it. However, the difference between results obtain in each of them allow to know if we will have some lateness. It could occur that the earliest starting date of the task j ES_j is after its relative latest starting date of the task j. But one task could not begin before its release date r_j, then it is not possible to start a task treatment before its ES_j.

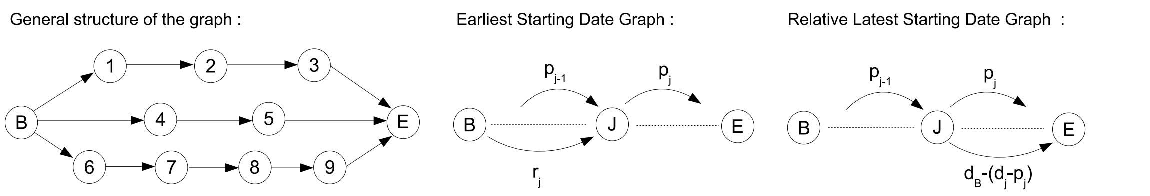

Fig. 2. Graph use to model the scheduling problem

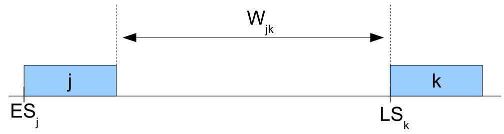

Fig. 3. Task insertion window

The real latest starting date of a task j is obtain as follow:

$$LS_j^E > ES_j \rightarrow LS_j = LS_j^E \tag{5}$$

$$ES_j > LS_j^E \rightarrow LS_j = ES_j \tag{6}$$

6.2 Time windows

In order to study the different place, within the schedule, where a new task could be inserted, we have to check time windows between tasks.

The computation of earliest and latest time for each task allows us to evaluate all the available time windows of the current schedule.

The situation, presented on the figure 3, describes a time window in a schedule. We observe here the classical case where earliest starting dates are before relative latest starting dates.

6.3 Insertion windows

A new task will have different characteristics which will allow us to evaluate the best place where insert it in the schedule. We have to search window large enough within time windows which are localized between the release-date and the due-date of the new task.

Windows will be sorted by their robustness level. If there is no window large enough within the totally robust windows, we will extend our research trough the most robust windows we can find. Within a windows set with an equivalent robustness level, we will work on ours secondary selection criteria which are the load balancing between ressources and the minimisation of the total working duration. Then we select the window which,after insertion, will minimize the workload standard deviation. As describe in figure 4, the deduction of the adequate insertion window will be done by variation simulation on the scheduling. The current planning and its possible variations will be simulated hundred times in order to obtain datas concerning the windows robustness.

In the next simulations, we will compare two cases. The aim of the first one will be to find the best location place to insert a new task as the maintenance manager would do it. The choice will be done by throuh minimisation of the workload standard deviation on the totality of the proposed windows. The second one has the same objective but it will use our methodology by simulating disturbances on the existing planning. That means that we will have to find the robustest insertion windows for new tasks. The minimisation of the workload standard deviation will be applied only on the set of the robustest windows.

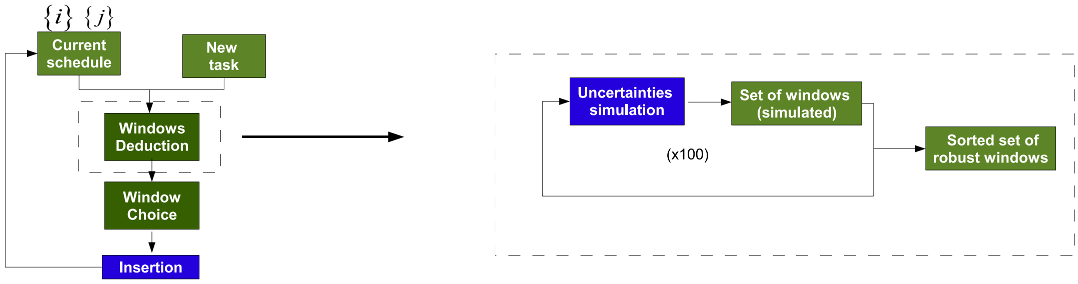

Fig. 4. Task insertion methode

After each task insertion the current planning is modified. Then, in case of a next insertion task, the new obtained planning will be used as the current planning and the last inserted task will also present variations.

6.4 computational method

As announced previously, we work in the case where a current planning exists. We will use the heuristic presented in [14]. Disturbance will be randomly generating on this planning, in order to observe the reality impact. Tasks which check $ES_j > LS_j^E$ does not have neither freedom movement degre nor temporal flexibility. They are also the sign of lateness observed by$ES_j + p_j > d_j$. This disturbances allow us to observe variations on the insertions windows sizes, as shown in the figure 3. While some might be shorter or longer than before, some might appear or disappear.

In a second time, windows will be compared to a new task j which has to be inserted. Being in an unrelated parallel machine context, the p_{ij} duration will depend on the resource who has the planning on which the window is studied. In order to show the interest of our proposition, we will insert teen tasks consecutively, in an existing planning. We will work on different sizes of problem and a large instances number. Insertion results will be obtain in polynomial time.

7 COMPUTATIONAL RESULTS

7.1 Data generation

We carried out a computational experiment on a Pentium IV 3.00GHz considering tests obtained by generating randomly the p_{ij} values. p_{ij} values are principally obtained by the combination of the basic tasks' duration (in time unit) which is an integer from the uniform distribution [1 , 7200]. This duration is multiplied by the competence level of the resource in the corresponding competence. For each task, a corresponding competence is determined by an integer from the uniform distribution [1 , 3]. It refers for each resource to a level, which is a real from the uniform distribution [1.01 , 2.00], in this competence. These data are determined before the simulation. Considering the resources and tasks number, the complexity is then $O(n*m)$. Penalties are determined as integers from the uniform distribution [1 , 10]. They are assigned if the task treatment is finished after its due-date, which is also obtained following a uniform distribution.The release-dates r_j are obtain as reels from the uniform distribution $[Now\ ,\ 86400u.t.]$ (Now being the simulation launching time) and the due-dates d_j are obtained as reels from the uniform distribution $[r_j + 2 * p_j\ ,\ r_j + 2 * p_j + 86400u.t.]$.

Concerning tasks duration perturbations, we assume that just a part of the total treatment time is sensible to a variation. The duration being composed by an incompressible part and variable part. Contrary to Esswein and al. who use a probability law in order to decide of the variations presence, we think that a schedule is made with tasks duration previsions [8]. Then the totality of the tasks is subjects to variations. The p_{ij}, r_j or d_j real values will be obtained by using a normal law on their variable part. Each time we generate disturbances, we make it hundred times and conserve the average.

7.2 Insertion algorithm results

A classical schedule, which does not take into account the possible disturbance, will search the different windows and will obtain a certain number of position. Our procedure consider the different disturbances

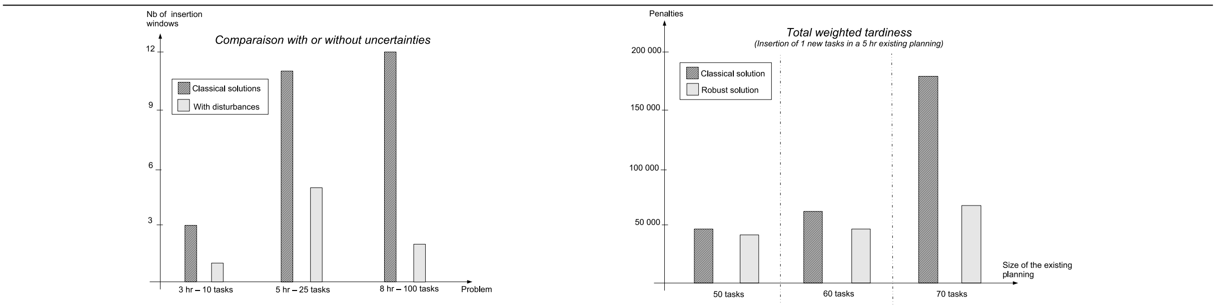

Fig. 5. Robustness and flexibility results

as explained before that is why we will compare insertion propositions on the same problem instances with and without uncertainties.

7.2.1 Insertion of one task

On the first graph in the figure 5, we compared the number of insertion windows which are proposed, in order to insert a task k, randomly generated. Perturbations are generated on 35% of each task duration with a standard deviation of 30%. The numbers of tasks (n) and human resource (hr) have been chosen to be representative from the reality. Results have been obtained on hundred computed instances. Our objective is to insert dynamically tasks in a current schedule. However, we can have a large set of possible choices. Windows real sizes can be longer and then it will be fine, but they could also be shorter. If the manager had chosen an insertion place which is, in reality, shorter than imagined, one task or more will be late. That is why it is really necessary to consider possible disturbance when we have to insert dynamically a new task. In the observed case with five human resources and twenty-five tasks, on the first graph in the figure 5, only 45% of the windows could be considerd as robust.

On the second graph on the figure 5 we observe total weighted tardiness obtained by three differents case studies. Here we show the efficiency of the method with an increasing existant load in a five human resources schedule. We based our study on three different load levels: fifty, sixty and seventy tasks already assigned in their plannings and generated within the same period. Results obtained are averages on teen simulations of insertions in each kind of planning. The interest for this method which has been shown here will now be completed with the case of insertions succession.

7.2.2 Insertion of teen tasks

In a second time we inserted dynamicaly teen new tasks in an existing planning composed of five human resources and fifty tasks. The table 1 show the results on six different current plannings. The comparison is the result of the average of hundred disturbances simulations on both final plannings. We can observed that the total weighted tardiness is really less important with our methodology.

We checked also the evolution of the total weighted tardiness, through the second example of the table 1, presented on the figure 6. When inserting the second task, results show that the location was not really performant. It comes from the fact that the simulation reflect the reality and even if we are in a proactive raisonning, the reality could be different than imagined. However, globaly results are better and after the insertion of the tenth task, results are nearly four times better with our method.

8 CONCLUSIONS

In this paper we observed uncertainties effect on existing schedules in an unrelated parallel machine context. In order to insert dynamically new tasks in a current schedule, we worked on the proactivity to find the set of robust places. We show, through exemples that the consequences of a bad choice (a non robust window) for dynamic insertions could, in case of variations, induce lateness. By inserting consecutive tasks in a current planning, we confirme that good results previously obtain on one dynamic insertion are valid and necessary in the multiple insertions case, which is closer to the reality. The fact to choose insertion windows by considering uncertainties, is a contribution in order to anticipate and to minimize the possible lateness. By minimizing the workload standard deviation between resources, we developed an approach which allow the load balancing between ressources but also the minimisation of

Table 1
Total weighted tardiness after the insertion of 10 new tasks.

Instance	1	2	3	4	5
Classical solution	97454	293580	355950	121168	152795
Robust solution	32065	68659	27958	47189	45220

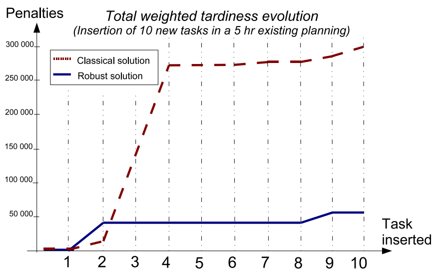

Fig. 6. Total weighted tardiness evolution

the total working duration. Our next works will consider cases where it is necessary to reschedule some tasks. We will also develop the multi-objectives aspect of this problem by considering also the workload balancing and the rescheduling impact on plannings.

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